18th International Conference - Science, Technology and Innovation
Booklets

RENIECYT
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RENIECYT - LATINDEX - Research Gate - DULCINEA - CLASE - Sudoc - HISPANA - SHERPA UNIVERSIA - Google Scholar DOI - REDIB - Mendeley - DIALNET - ROAD - ORCID

Title: A didactic platform for the study of Linear Quadratic Regulator (LQR) control for Trajectory Tracking of dc motor

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Editorial label ECORFAN: 607-8695
BECORFAN Control Number: 2021-01
BECORFAN Classification (2021): 131221-0001

Pages: 22
RNA: 03-2010-032610115700-14

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Introduction

- In universities the study of automatic control is necessary for the training of future engineers.

- A didactic platform was developed for the study of LQR control in an experimental way.

- A cd motor was selected because its torque, position and angular velocity can be controlled only by varying the input current.

Methodology: LQR control for trajectory tracking

The control of linear dynamical systems with quadratic criterion consists of a linear dynamical system

$$x'(t) = Ax(t) + Bu(t)$$

And a cost function

$$J(t_0, x, u) = \frac{1}{2}\int_{t_0}^{t_1} [x^T(t)Qx(t) + u^T(t)R_C u(t)]dt + x^T(t_1)S_1 x(t_1)$$

Where S_1 and Q are semi-definite positive matrices and R_C is a positive definite matrix.

Methodology: LQR control for trajectory tracking

A u^* control is sought such that:

$$J^*(t_0, x) = J(t_0, x, u^*) = min_{u\ in\ U} J(t_0, x, u)$$

The $J^*(t_0, x)$ function is known the value function of optimal control problem, where $u^*(t)$ is the optimal control.

Methodology: LQR control for trajectory tracking

Using the Dynamic Programming Technique or the Pontryagin Maxim Principle it is possible to obtain optimal control.

$$u^*(t) = -R_C^{-1}B^T P\,(t)x(t) \rightarrow u^*(t) = -Kx(t)$$

Where $K = R_C^{-1}B^T P(t)$ is the feedback gain and $P(t)$ is the solution of Ricatti's differential equation.

$$P'(t) + A^T P(t) + P(t)A - P^T B R_C^{-1} B^T P(t) + Q = 0$$

Methodology: LQR control for trajectory tracking

The augmented system is studied

$$x'(t) = Ax(t) + Bu(t), \qquad \xi'(t) = r(t) - Cx(t)$$

With optimal control signal

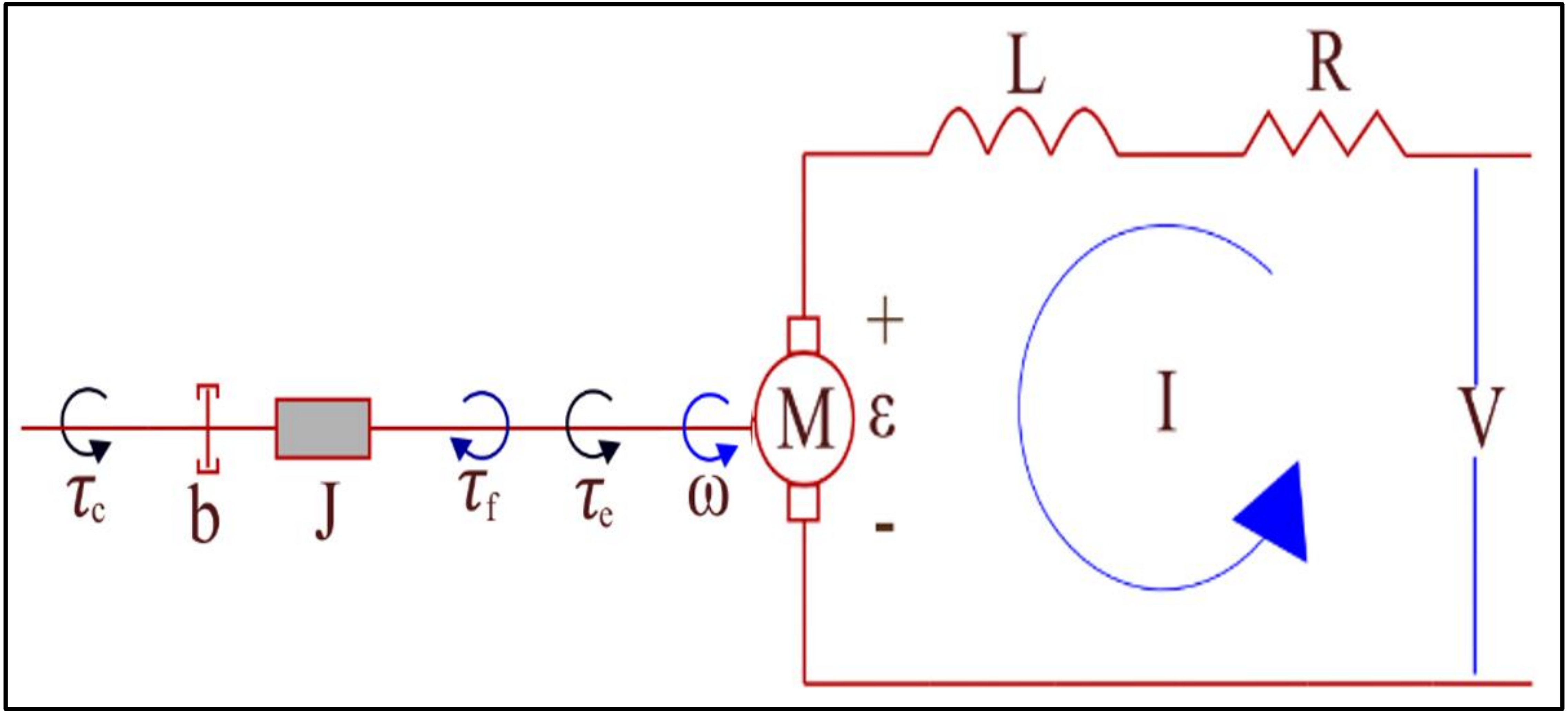
$$u^*(t) = -R_C^{-1}\bar{B}^T P(t)\bar{x}(t), \qquad u^*(t) = K\bar{x}(t)$$

Where: $\bar{x} = \begin{bmatrix} x'(t) \\ \xi'(t) \end{bmatrix}$, $K(t) = -R_C\bar{B}^T P(t)$, and $P(t)$ is a solution of Ricatti's differential equation: $P'(t) + \bar{A}^T P(t) + P(t)\bar{A} - P^T(t)\bar{B}R_C^{-1}\bar{B}^T P(t) + Q = 0$

Where $\bar{A} = \begin{bmatrix} A & 0 \\ -C & 0 \end{bmatrix}$ y $\bar{B} = \begin{bmatrix} B \\ 0 \end{bmatrix}$

Methodology: Modelling of DC motor

The electrical and mechanical diagram of the DC motor.



Methodology: Modelling of DC motor

Variables Used in the DC motor

Símbolo	Variable	Unidades
V	DC motor voltage	V
I	Dc motor current	A
R	Armature resistance	Ω
L	Armature inductance	H
ϵ	Induced electromotive force	V
ω	Angular velocity	Rad/seg
J	Rotor inertia	Nm^2
b	Viscous friction coefficient	N/ms
τ_e	Electromechanical torque	Nm
τ_f	Friction torque	Nm
t_c	Resulting torque	Nm
k	DC motor count	

Methodology: Modelling of DC motor

When performing the mechanical and electrical analysis, the equations are arrived at:

$$\frac{d\omega(t)}{dt} = -\frac{b}{J}\omega(t) + \frac{k}{J}I(t) - \frac{1}{J}m_s(t)$$

$$\frac{dI(t)}{dt} = -\frac{k}{L}\omega(t) - \frac{R}{L}I(t) + \frac{1}{L}V(t)$$

These equations can be expressed as

$$x'(t) = Ax(t) + Bu(t) + Gw(t)$$

$$x(t) = \begin{bmatrix} \omega(t) \\ I(t) \end{bmatrix}, \mathrm{A} = \begin{bmatrix} -\frac{b}{J} & \frac{k}{J} \\ -\frac{k}{L} & -\frac{R}{L} \end{bmatrix}, B = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{L} \end{bmatrix}, u(t) = \begin{bmatrix} 0 \\ V(t) \end{bmatrix}, G = \begin{bmatrix} -\frac{1}{J} & 0 \\ 0 & 0 \end{bmatrix}, w(t) = \begin{bmatrix} m_s(t) \\ 0 \end{bmatrix}$$

Methodology: Estimation of DC motor parameters

An SKF static Analyser Baker Dx was used to determine the value of resistance and inductance.

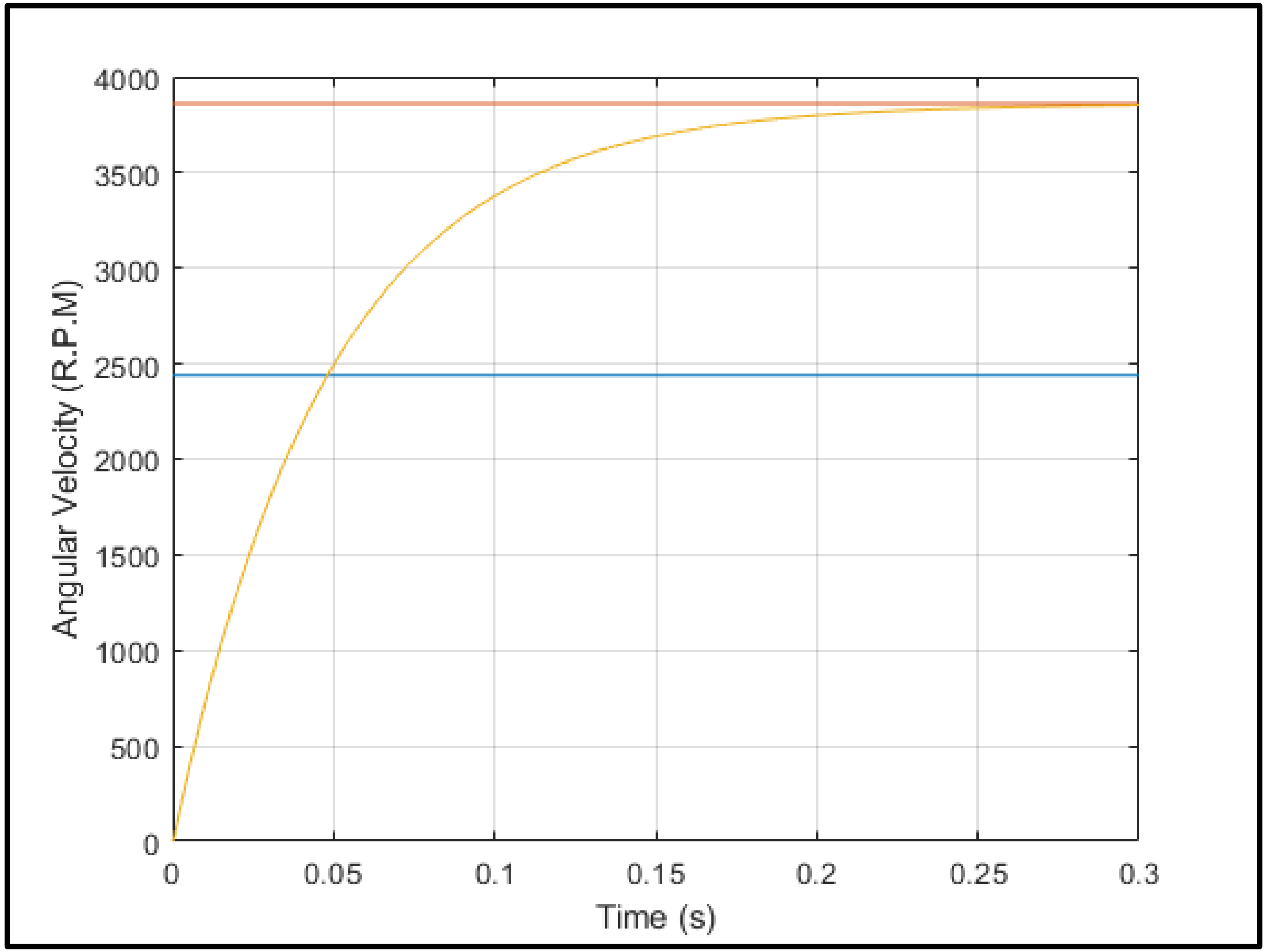
For the DC motor constant: $k = \frac{V(t) - RI(t)}{\omega(t)}$

For the viscous coefficient of friction: $b = \frac{kI(t)}{\omega(t)}$

For the moment of Inertia: $J = \frac{\tau k^2}{R}$, where τ is the time constant, obtained by applying a constant voltage to the motor and measuring the time it takes to reach 63.21% of its final angular velocity.

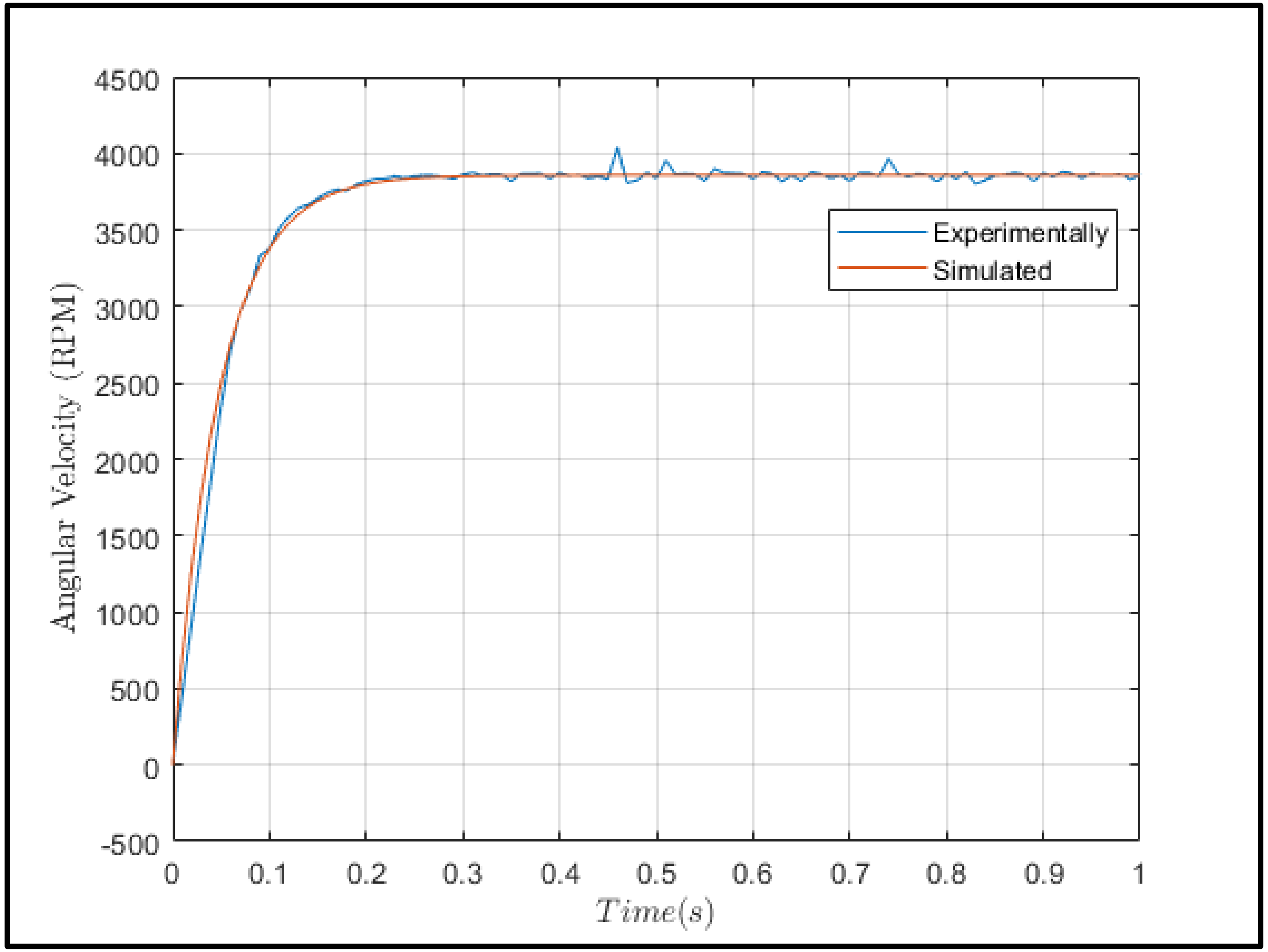
Methodology: Estimation of DC motor parameters

Graph to calculate the time constant



Methodology: Validation of DC motor parameters

Angular velocity of DC motor in simulation and experimental

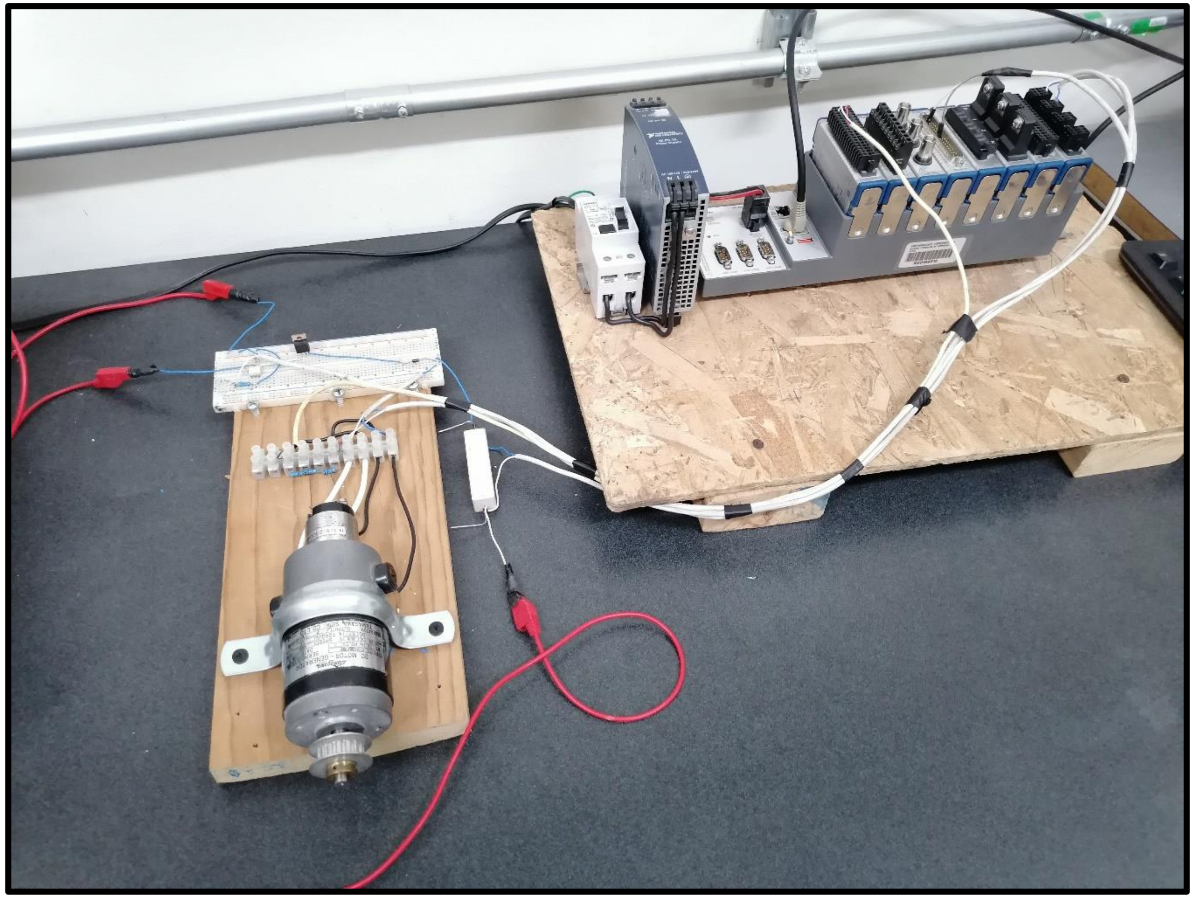


Experimentally obtained DC motor parameters

Variable	Value
b	33.087 $\mu Ns/m$
J	11.414 μNm^2
k	0.0504
R	12.4522 Ω
L	2.6 mH

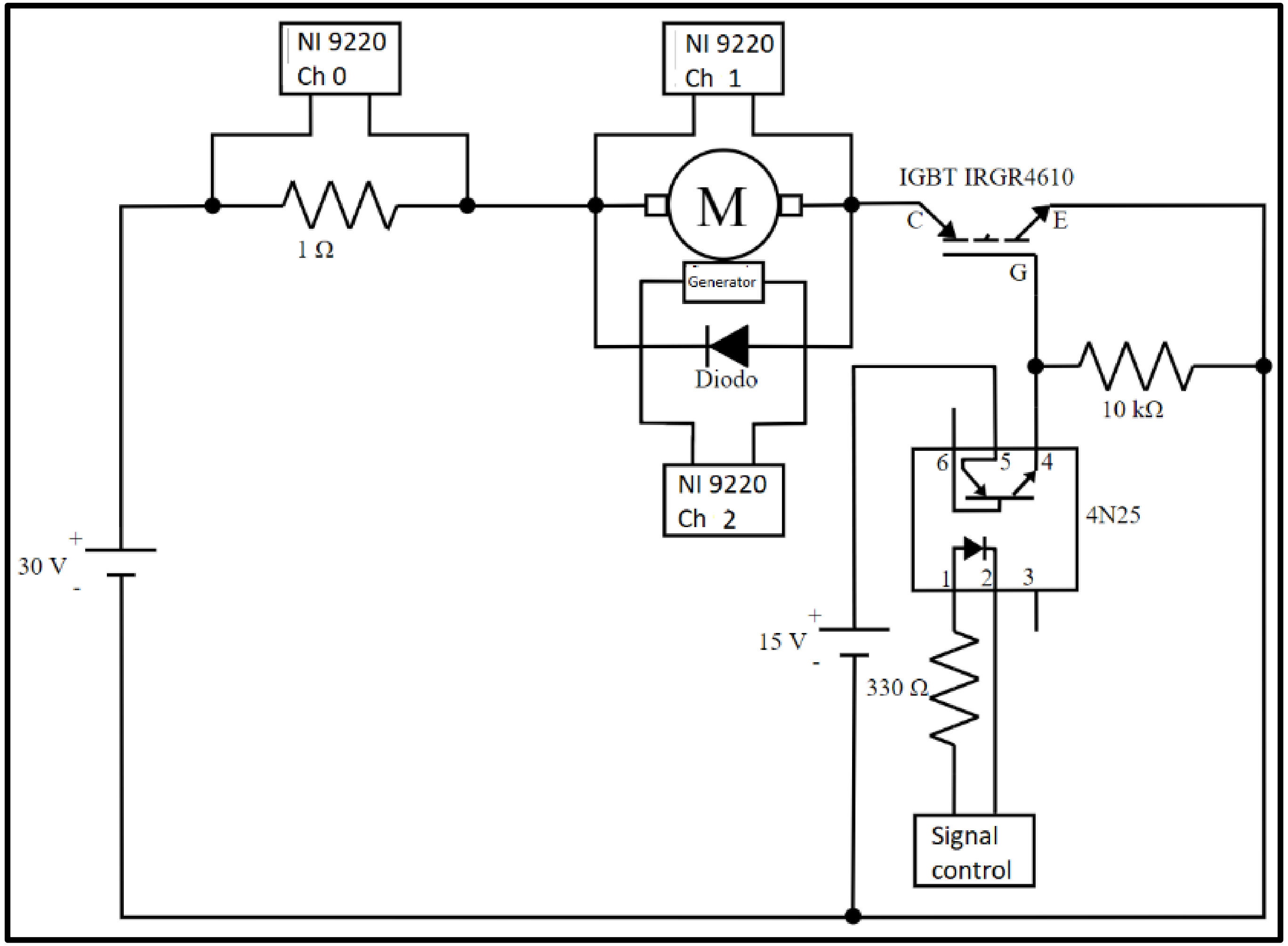
Methodology: Didactic platform for the LQR Control demonstration

Didactic platform composed of a generator-motor and a compact Rio (CRio) data acquisition system (SAD) and input and output cards.



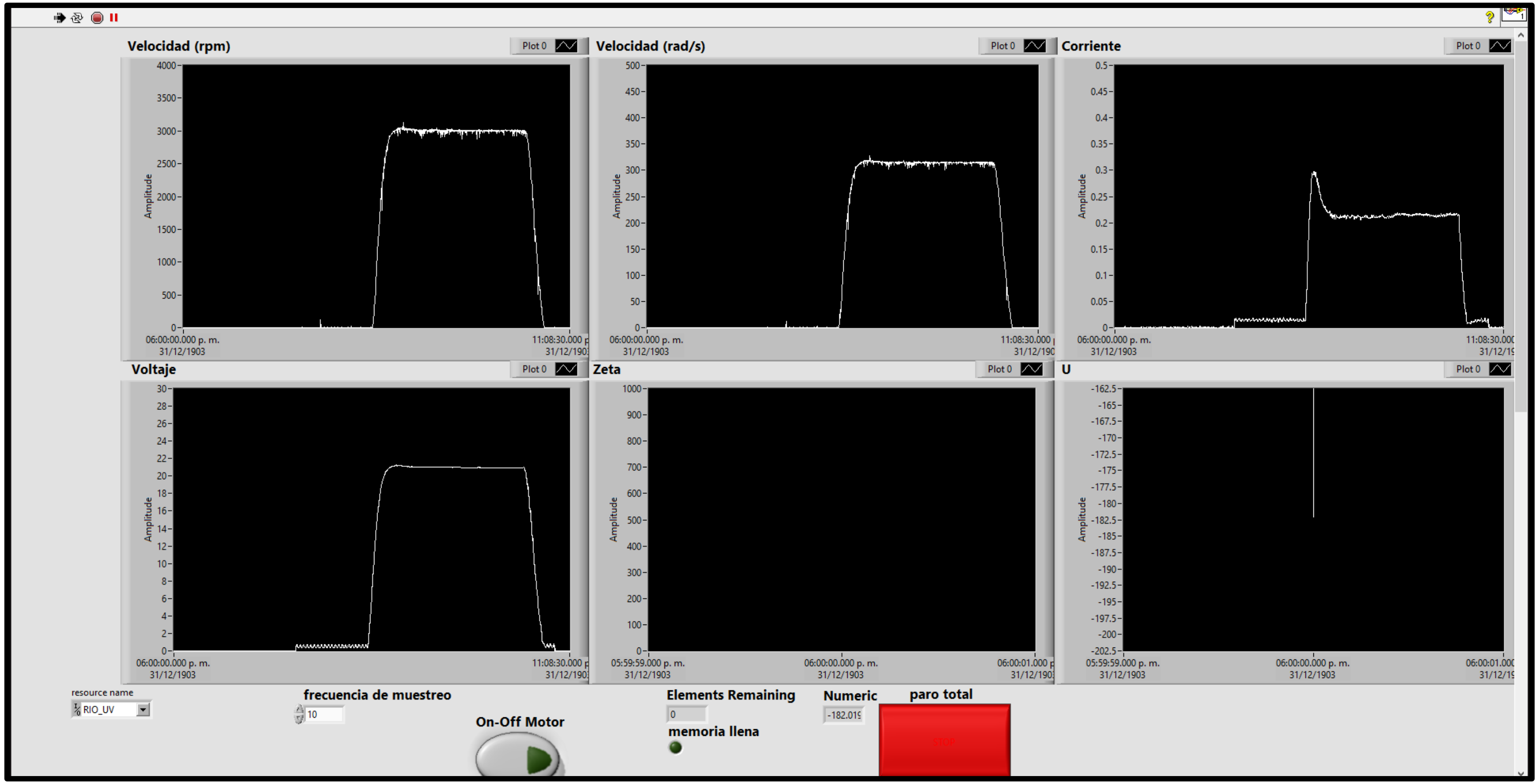
Methodology: Didactic platform for the LQR Control demonstration

Electrical diagram of the prototype.



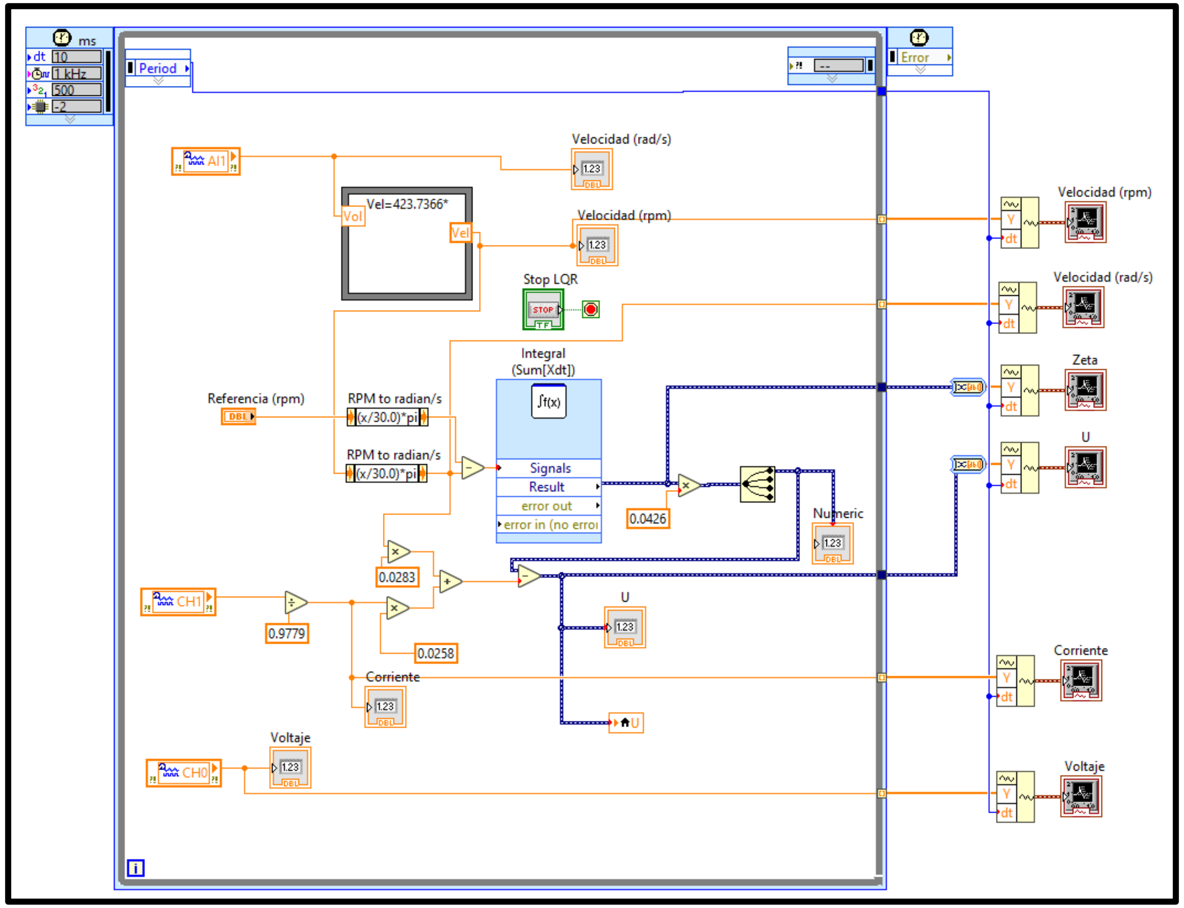
Methodology: Didactic platform for the LQR Control demonstration

Interface man machine (HMI) where you can control the on or off, of the dc motor, graph the speed, current and voltage of the dc motor.



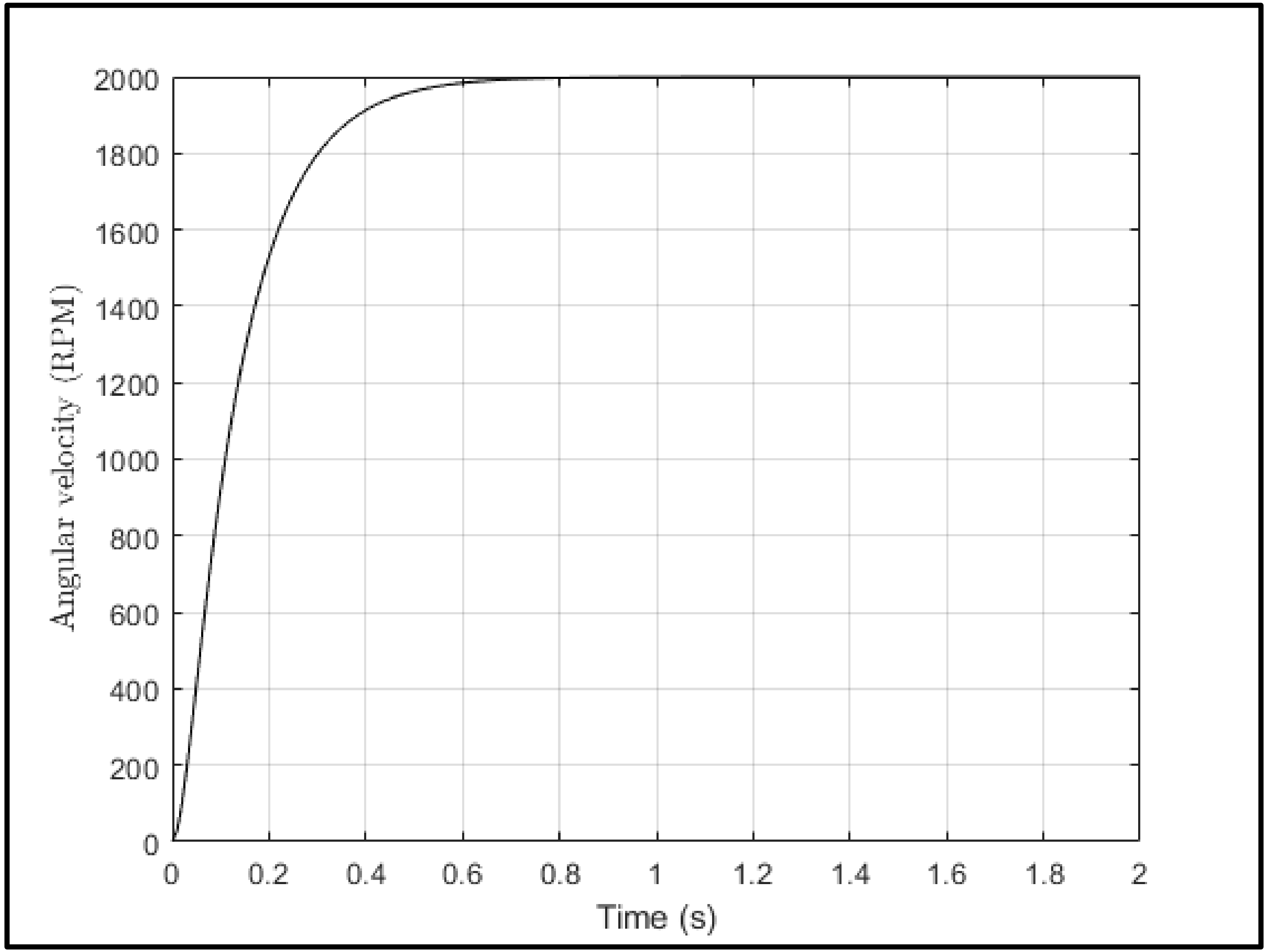
Methodology: Didactic platform for the LQR Control demonstration

Program in LabVIEW with which the LQR control was programmed and to be able to apply it experimentally in the dc motor.



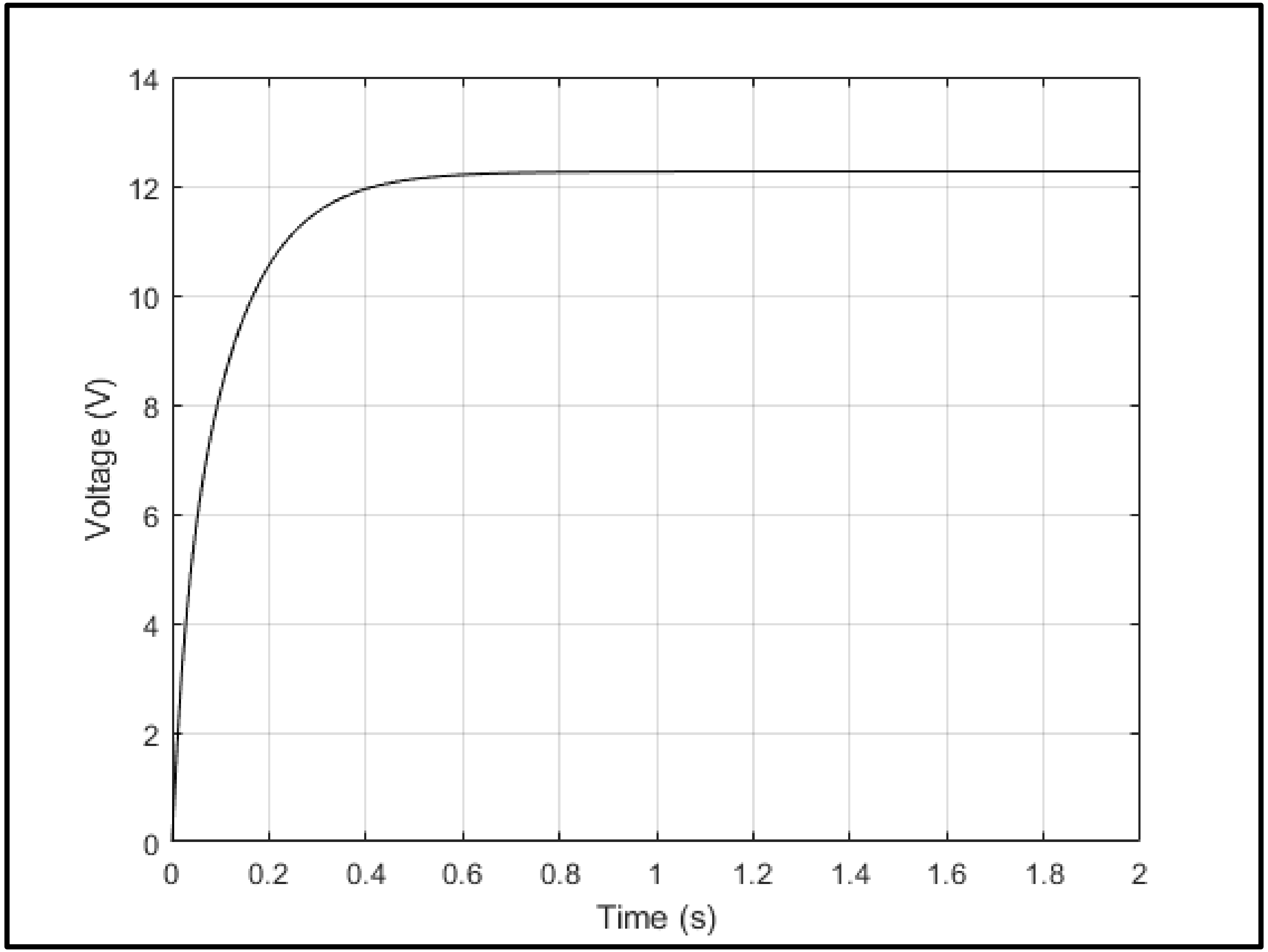
Results

DC motor Speed with Simulated LQR Control



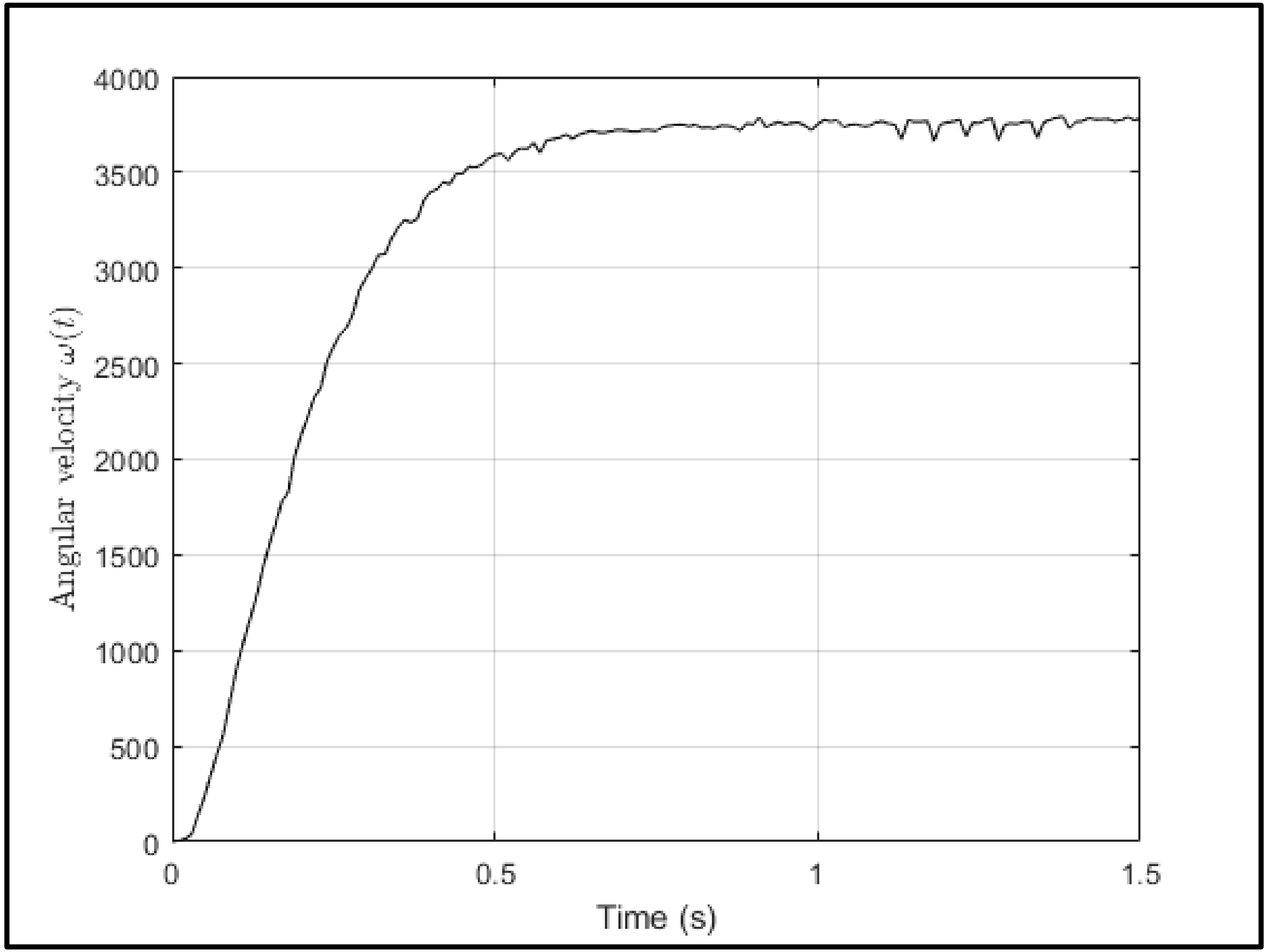
Results

Control Signal Speed



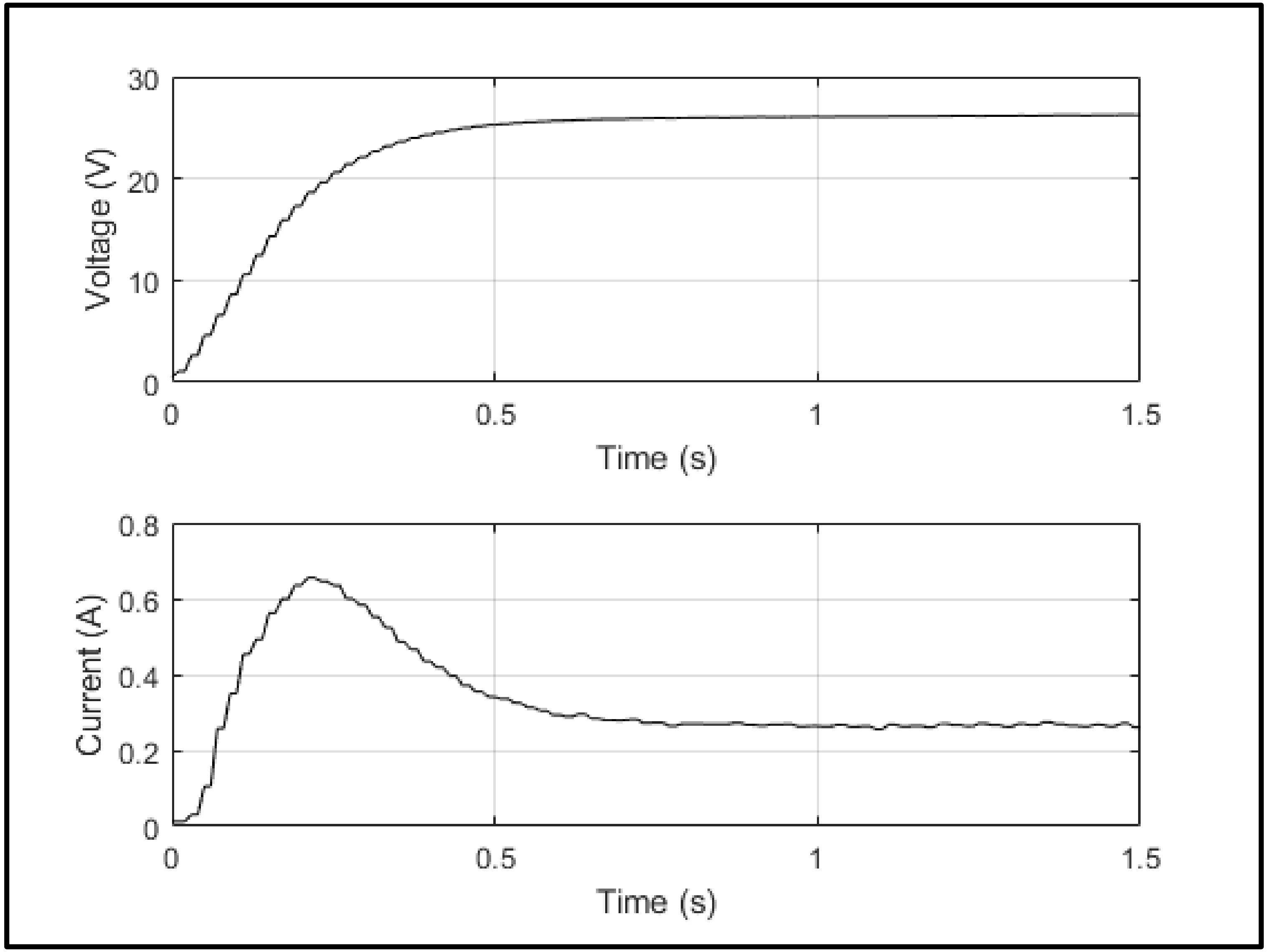
Results

DC motor Speed with Experimental LQR Control



Results

DC Motor Voltage and Current Graphs



Conclusions

- This work presented the design of a didactic platform for the study of LQR control for trajectory tracking in a DC motor, the objective is to control the angular velocity and bring it to a reference position in real time was achieved.

- LQR controllers are generally applied in simulation, one of the goals of this work is to show the methodology that was used to be able to apply the LQR control experimentally in a DC motor.

- Simulation of the LQR control was carried out with Matlab software obtaining results similar to those obtained experimentally, in both cases it was verified that the angular velocity of the dc motor follows the reference signal in a finite time and with a control signal within the voltage parameters that the motor supports.

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